2017

Municipal Climate Adaptation Guidance Series: Transportation

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This guidance document is one of a series that was developed collaboratively by the Municipal Planning Assistance Program of the Maine Department of Agriculture Conservation and Forestry, and the following regional planning organizations:

Androscoggin Valley Council of Governments
Greater Portland Council of Governments
Hancock County Planning Commission
Kennebec Valley Council of Governments
Lincoln County Regional Planning Commission
Midcoast Council of Governments
Mid-Coast Regional Planning Commission
Northern Maine Development Council
Southern Maine Planning and Development Commission

This guidance document was funded under awards CZM NA14NOS4190066, NA16NOS4190018 to the Maine Coastal Program from the National Oceanic and Atmospheric Administration U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration or the Department of Commerce.

Introduction

A local road system consists of a network of components (e.g., roadways, bridges, culverts, etc.) that is owned and maintained by a city, county or other municipal transportation agency with little or no federal funding. Local road systems invariably are part of a larger network and decisions by one entity may affect regional transportation capacity if a local road is affected by any natural or man-made hazard.

By their very nature, local road systems are exposed to flooding and rainfall-runoff. Roads traverse the landscape, sometimes following along waterways and sometimes striking out across country without regard to hills, valleys and streams. Road systems, composed primarily of paved and unpaved roads and various types of structures that cross waterways, experience a range of damage. Damage results from rising creeks and rivers as well as from runoff due to locally intense rainfall.

Flooding affects both the short and long-term performance of local road systems and can affect communities in many ways, including increasing the potential for life loss and injuries, creating shortfalls in community budgets, delaying planned maintenance work because manpower and funds are diverted to recovery, disrupting normal traffic patterns, and stranding residents. Local governments typically are organized to include agencies that are charged to manage the local road system.

Various engineering, system-enhancement, and emergency-response strategies can be implemented to reduce the impacts of flooding. Each risk-reduction strategy – referred to as mitigation – has implementation costs and some residual risk of unacceptable performance will always be associated with floods that are larger than the design flood. A minimal approach (e.g., the “do- nothing” strategy) will have relatively low implementation costs but the residual risk of unacceptable system performance may be relatively high (perhaps unacceptably high). At the opposite end of the spectrum, aggressively pursuing mitigation will have high (perhaps unacceptably high) implementation costs but the residual risk of unacceptable performance will be small.

Just what constitutes unacceptably high implementation costs and unacceptably high residual risk depends on the constraints (economic, political, and legal) under which the responsible agency operates. It is generally understood that acceptable risk is owner and stakeholder acceptance of that level at which additional costs to implement mitigation measures to further reduce losses and risks are no longer acceptable. There is no standardized method by which individual communities perceive and address risk associated with local road systems.

In a pure sense, quantitative estimates of how much it costs to provide any given degree of flood- resistance, and the direct and indirect benefits of doing so, can be developed for any risk- reduction strategy. However, as a practical matter, just how costs and benefits are taken into consideration by local road departments when determining risk and selecting risk-reduction strategies differs from one community to another. This is because of variations in geographic, economic, capability, capacity, and regulatory influences.

Flood-related damage to paved and unpaved roads, road shoulders, ditches, culverts and structures over waterways may be caused in several different ways. The three general types of flooding are:

- River and Stream Flooding occurs when rainfall generates runoff such that the volume of water conveyed in waterway channels exceeds the capacity of those channels and flows into flood hazard areas, commonly called floodplains. The standard typically used for flood hazard area identification and land management is the 1%-annual chance flood, commonly called the 100-year flood.
- Coastal Flooding occurs from storm surges and sea level rise. Storm surges are event based and cause temporary flooding. Impacts from sea level rise start by causing more frequent occurrences of 'nuisance flooding' when high tides impact roadways on king or annual high tides or even monthly high tides and progress to more frequent flooding events and potentially to total inundation from higher overall sea levels.
- Heavy Runoff occurs when intense rainfall generates concentrated runoff that either exceeds the capacity of drainage roadside ditches and underdrains or that flows where ditches and drains are not provided.

Roads and Drainage

Many places within Maine are experiencing damage to roads and drainage elements from the general types of flooding described above. The term "damage" is used broadly and ranges from localized ditch scour to complete collapse of a length of road bed or embankment. The nature of damage to roads and drainage elements includes but is not limited to the following:

- Saturation and collapse of inundated road beds;
- Loss of paved surfaces through flotation or delamination;
- Washout of unpaved roadbeds;
- Erosion and scour of drainage ditches, sometimes to the extent of undermining shoulders and roadbeds;
- Damage to or loss of underdrain and cross-drainage pipes;
- Blockage of drainage ditches and underdrain by debris, exacerbating erosion and scour;
- Undermining of shoulders when ditch capacity is exceeded;
- Washout of approaches to waterway crossings; and
- Deposition of sediments on roadbeds.

Often, the total cost for repair of damage to side ditches, underdrain and cross-drainage pipes, shoulders, unpaved roads and paved surfaces and road beds exceeds the total cost of damage to bridges and culverts that cross waterways. Further, a large part of the damage does not occur in what are generally considered floodplains along rivers and streams, but is a result of locally intense rainfall-runoff.

Waterway Crossings

Roads over waterways are supported by bridges, culverts, and low-water crossings as described below:

- Bridges. Generally, a bridge is composed of abutments on both waterway banks that are designed to support the bridge deck, driving surface, traffic loads, and other loading conditions (e.g., wind, seismic, snow load, etc.) A bridge may have intermediate supporting piers.
- Culverts. Culverts may be rectangular box structures that are site-built, or prefabricated units that range in shape from circular, to oval, to arched (sometimes bottomless).
- Low-Water Crossings. Low-water crossings allow vehicle passage and are intended to be under water all or some of the time. There are two general types: permanent concrete slabs (with or without small diameter pipes) and gravel embankments (with small diameter pipes) which form the driving surface.

For the purposes of inspections required by the U.S. Federal Highway Administration, specific definitions that vary from the common usage are used. The federal definition of a “bridge” is a structure having an opening that is more than 20 feet wide and may include multiple pipe or box culverts. A “culvert” is a structure having an opening that is 20 feet or less in width. Because the definition is based on the width of the waterway opening, a structure that is built like a bridge (abutments and superstructure) may be called a culvert.

The nature of damage at waterway crossings can include, but is not limited to the following:

- Local scour at piers and abutments with and without permanent structural damage;
- Downcutting of streambeds, which may affect bridge abutments/piers and undercut culvert inlets and outlets;
- Washout of gravel low-water crossings;
- Deposition of bed load that restricts the hydraulic capacity of crossings;
- Debris accumulation that may contribute to backup of water and damage to adjacent properties;
- Shifting of bridge decks due to pressure of rising floodwaters; and
- Shifting or migration of waterway channel alignment

Factors that Influence Transportation Flooding Decisions

This section discusses how flood risk-reduction decisions are affected by flood hazard data/maps and past experience with flood damage. First, there is brief background on the 1%-annual chance (100-year) flood which is the basis for flood hazard maps that are prepared by the National Flood Insurance Program (NFIP). Whether shown on a map or simply known through experience, flood hazards influence a town's Public Works general operations, efforts to comply with regulations, and evaluation and selecting waterway crossing designs.

Flood Hazards

The Federal Emergency Management Agency creates maps showing areas at varying levels of flood risk from naturally occurring events. These delineations are based on watershed studies and analysis of historical storm events. The maps provide the basis of eligibility for the National Flood Insurance Program and are frequently used in transportation infrastructure design. Following enactment of the National Flood Insurance Act in 1968, the 1%- annual chance flood (commonly called the 100-year flood) became the basic standard for delineating areas at risk from flooding. However, these maps are based solely on looking at historical conditions and do not currently take projected sea level rise or increasing levels of precipitation into account in their portrayal of floodplain locations. With changing climate conditions, designing or regulating based on the 1% conditions shown on flood maps may not provide the intended level of protection. Using the floodplain of the 0.2 % storm (commonly called the 500-year storm) is becoming a more common design standard to increase the resilience of transportation to future flooding and storm conditions but data on the 0.2% storm is not available for all communities.

> Does a 100-year flood mean it only occurs once every 100 years?
>
> No. What it means is that there is 1% chance that a flood of that extent could occur in any particular year. A 25-year flood has a 4% chance of occurring in any particular year; a 500-year flood has a 0.2% chance of occurring in any particular year.

Actual flood experience also plays an important role is design considerations. This appears to be for two reasons. The primary reason is that Public Works professionals deal with some degree of flooding nearly every year and do not depend on an external source of information to tell them where flooding is likely. They know that any drainage way can experience the effects of high water, whether it is a river, perennial stream, ephemeral stream, or simply a drainage ditch. The second reason is that not all municipalities have FEMA flood hazard maps based on detailed engineering studies; these maps show approximate flood hazard areas without sufficient information to support actual design.

Flood Hazards and Experience: General Public Works

Local road systems may be exposed to flooding and damage due to rising rivers and streams, to intense storms that generate rapid runoff and, depending on location, to storm surge and sea level rise. The nature of flooding and the potential for damage is usually well understood by municipal Public Works departments, as is the objective of flood resistance. Actual flood experience exerts a very strong influence on decisions made by Public Works departments especially flooding that has occurred within the tenure of the current directors. Public Works departments also recognize that local roads will always be exposed to some degree of flooding, and therefore, flood resistance does not mean "damage-free." This is especially likely for the many existing flood prone waterway crossings where multiple constraints often do not allow them to achieve the desired degree of flood resistance even when a crossing is replaced.

Whether flood damage has been localized or widespread, some degree of flood resistance can "sell itself,". Decisions to incur incremental, though undefined, costs to improve flood resistance may be made without explicit approval from higher authorities depending on constraints within an agency's maintenance budgeting. Although these decisions are invariably moderated to some degree by budgetary and other constraints, the decisions demonstrate the desire of Public Works to achieve at least some minimum tolerable level of acceptable performance of the roadway system (corresponding to some maximum tolerable level of acceptable risk). These decisions may be thought of as equivalent to an "acceptable- risk" approach, although many Public Works departments do not officially set specific acceptable-risk levels.

Work that is done with state or federal funds (primarily structures with spans longer than 20 feet) must comply with certain conditions, including flood-resistance requirements. Work that is done without those funds typically accommodates a "target" flood discharge for improved flood resistance that may be less than would otherwise be specified in conditions attached to state or federal funding. Sometimes the degree of success is limited by other constraints, including budget, impracticality at specific sites or measures that cannot be constructed with in-house crews. However, even in cases where conveying the target flood discharge cannot be achieved, Public Works should take whatever steps are available to reduce the impacts of flooding to the greatest practical extent.

Flood Hazards and Experience: Roads and Drainage

The primary mission of a municipality's Public Works department is to serve the public by maintaining and improving the local road system. Improving flood resistance is an integral part of that mission –not only to save resources and time following future floods but also to provide future savings in the form of damage avoided.

Improving flood resistance is implemented to different degrees and in different ways, largely as a function of the frequency of flooding, vulnerability to damage, the nature of past damage, constraints imposed by funding sources and permitting authorities, a community's resources, capabilities, and budget. It is standard civil engineering practice to design installations to handle a target flood discharge. The target flood discharge may be established by state regulations, as a condition of a permit, as a condition of a funding source, or by the Public Works internal objective to improve hydraulic performance. In the past, the target discharge used most frequently has been the 1% annual chance flood. Implicit in using runoff calculations based on frequent storms is that less frequent storms that produce more runoff will exceed the drainage capacity – although that, in and of itself, does not necessarily lead to damage.

Public Works departments make many decisions about their existing roads and drainage system components, and those decisions are influenced to some degree by consideration of runoff. For the most part, those decisions are not based on site-specific engineering; rather, they are based on common practice, experience and observations about what is effective. It is important to note that many such decisions are made by crew supervisors who have the authority to exercise judgment on such matters based on field conditions.

It is difficult to accurately delineate areas where runoff damage is likely to affect the road system drainage ditches and drainage pipes. Such damage may occur anywhere; it depends on where the heavy rainfall-runoff occurs, and not necessarily on where rivers and streams rise out of their channels. It also can be affected by conditions, not readily visible, that reduce culvert capacity such as impacted debris, beaver dams, etc. Sometimes drainage system components have been in place for decades and were not engineered for current site- specific conditions. Surrounding land use and land use changes can have dramatic effects on run-off and its associated impacts to roadways and drainage systems. Single developments with large cleared areas, increased area of impervious surface, and cumulative effects of development over time all result in an increase in the amounts of run-off that can cause devastating impacts on transportation systems that previously functioned without problem.

The Influence of Budgets

Sources and amounts of funding are factors that influence the ability of a municipality to maintain its local road system to the preferred level of functionality, including ability to restore safe functioning after flood damage occurs. Some communities may have significantly more funding options than others, but few are insulated from the unpredictability of internal budget processes and the variability of funding from external sources. When local funding is provided, the governing body usually specifies a target amount for the Public Works to plan for each year's budget. That amount is typically influenced by the department's reports of maintenance and capital project needs and does not include emergency repair and replacement needs.

The occurrence of flood damage places additional demands on the budget, since funding that was allocated for routine maintenance would instead need to be diverted to recovery operations. However, some Public Works departments establish special funds that are set aside for recovery, which moderates the adverse effect that floods have on the budget and should be considered a best practice to increase community resilience. In addition, departments that maintain good records of the extent of flood damage and the costs associated with damage repair can in some instances recover a portion of such costs from FEMA.

The Influence of Local Knowledge and Experience

The experience and knowledge of individual staff (both engineering staff and field crew supervisors) have an important influence on decisions about flood resilience issues. The past performance of individual bridges and culverts that have been exposed to flooding is another form of local experience that is very influential. Local knowledge and experience with flood-risk reduction measures that are implemented and subsequently tested during an actual flood are an important influence on subsequent decision making by municipalities.

The Influence of Staff and Equipment Capacity

Maine Public Works generally determine their current staffing levels (number and skill mix) and equipment requirements (types and sizes) based on their anticipated normal work load. Not surprisingly, budget constraints are a significant constraint on actual staff and equipment capacities such that staffing and equipment needs may fall short of those requested.

In-house capacity for engineering structural design of bridges and culverts varies due to the size of the community and budget. Some Maine communities have in-house engineering capacity while most do not. Those communities with engineering capacity have the ability to do site-specific designs. Communities without in-house engineering capacity contract out for the service when needed or rely on generic structural designs prepared by others.

The Influence of Inspections

Periodic inspections of roads and crossings yield data that, in large measure, guide decisions about road and drainage maintenance, as well as decisions about rehabilitation and replacement of waterway crossings. Bridges and culverts with spans longer than 20 feet are inspected every other year, in compliance with federal requirements. The resulting sufficiency and condition ratings should also be used to influence decisions on work other than routine maintenance. However, it is notable that, although inspections will identify scour and erosion that could affect structural stability during a flood, the purpose of the inspections is not to determine the adequacy of hydraulic performance. Culverts less than 20 feet tend to receive much less scrutiny. The results of these inspections strongly influence the selection of structures for rehabilitation and replacement. When a structure is selected for rehabilitation or replacement for any reason, it is a good time to consider measures for improving performance under flood conditions.

The Influence of Immediate Post-Flood Recovery

The primary mission of local Public Works is to provide good local roads for the safety of the traveling public. This mission is unchanged when flooding affects the system, but the efficiency and thoroughness with which recovery is accomplished can be challenging.

Particularly challenging are the short and long-term impacts on the budget. Paying for flood recovery, if not specifically planned and budgeted beforehand, results in diversion of funds from routine maintenance and planned capital projects. If this diversion of funds is not compensated by an infusion of other local funds and reimbursement from state and federal sources, previously scheduled maintenance and projects will be delayed. If multiple damaging floods occur within a short period of time, or if adequate funding is not restored, then the net result is an overall reduction in the quality of the local road system.

Flood and runoff damage to local road systems can occur with regularity, and most of these events may not qualify for federal disaster assistance. This experience, and the expectation that flooding will likely cause some degree of damage every year, should influence municipalities to budget for flood recovery in the form of a special account that can accrue from year to year.

Quick and efficient post-flood response by a Public Works departments can conflict with the expectations of some state and federal inspectors. Some inspectors may challenge re imbursement requests or limit approved amounts for two reasons: either the work was performed prior to inspection, or documentation of the extent of damage is inadequate. As a result, the communities can perceive that they are penalized for having capable and responsive workforces. Furthermore, efforts to increase the capacity of replacement structures may conflict with state or FEMA reimbursement guidelines.

The Influence of Implicit Consideration of Costs and Benefits

There is no standardized method by which individual communities perceive and address risk, nor is there a standardized method for considering all costs and all benefits. However, most places include some implicit assessment of costs and benefits when making decisions about specific capital projects and routine maintenance. Due to dwindling budgets, they are keenly aware of the need to invest wisely. Given the many factors that influence decision making, including political pressures, decisions may not always be based solely on measurable costs and benefits.

For any given capital project to upgrade or replace a waterway crossing, a full accounting of direct costs can be developed. Direct costs are those associated with the engineering for design and with the labor, equipment, and materials for construction. Indirect costs are other costs that are associated with a project, such as increased di stance and time traveled if a detour is required. For local roads that are important to local industries, indirect costs may be significant.

Another component of a cost/benefit determination can be the identification of damages avoided. Thus, a structure or road segment that experiences flooding but does not sustain damage may accrue a benefit, the value of which is the avoided costs to repair flood-induced damage. It should be noted that a full accounting of such benefits may be difficult.

Many communities do not perform – and do not express interest in performing – rigorous analyses to estimate all costs and all benefits. This is partially due to the perception among the municipalities that these methods may possibly limit their ability to balance the many factors that influence all their decisions.

Although the Public Works departments usually develop some form of cost estimate for capital work, most of these estimates are not prepared in great detail – particularly when the work is to be performed in-house. In those cases, the estimates are simply based on the costs of similar work performed recently (which are available due to their detailed record keeping). However, cost estimates are typically prepared after decisions have been made regarding the desired level of performance (e.g., elevation of approach road, width of the road surface, waterway opening size to convey the target discharge, etc.). In some projects, cost estimates for different configurations are prepared. However, these will pertain to, say, comparing a bridge to a box culvert, rather than comparing incremental costs of different degrees of flood resistance. Thus, it would be difficult to separate out costs specifically associated with flood resistance.

In addition, cost estimates that are prepared before departments fully understand state and federal permitting requirements may, in some cases, substantially underestimate full project costs. Structures that are used by migrating or protected fish species, for example, may need to be larger or of a more rigorous and expensive design than would otherwise be suggested simply on a hydraulic basis.

Most communities do not attempt to quantify the myriad benefits of a safe and fully functional local-road system. Nor do they make a full accounting of all direct and indirect costs associated with improving flood resistance – much less all direct and indirect benefits. Municipalities mostly factor economic importance into their long-term planning for road and crossing improvements, but any balancing of costs and benefits is done is based on experience rather than detailed calculations.

A municipality essentially decides about cost effectiveness related to improving flood resistance when it finds that the incremental cost of the next larger size pipe or a somewhat longer bridge superstructure is small, while the labor costs do not vary significantly. However, the degree of improvement associated the next larger size or the somewhat longer bridge is not quantified.